THOMPSON

METHODS OF PHYSICAL SCIENCE

THE METHODS

OF

PHYSICAL SCIENCE.

A LECTURE

DELIVERED AT UNIVERSITY COLLEGE, BRISTOL,

AS INTRODUCTORY TO THE COURSE OF 1877-8.

BY

SILVANUS P. THOMPSON, B.Sc., B.A.

Lecturer in Experimental Physics at University College, Bristol.

Fellow of the Royal Astronomical Society.

Member of the Physical Society of London, &c.

BRISTOL :

THOMAS KERSLAKE & CO.

LONDON :

MESSRS. LONGMAN & CO.

1877.

THE METHODS OF PHYSICAL SCIENCE.

In former days when few men busied themselves with the phenomena of the world around them, when travelling was difficult and knowledge inaccessible, and when as yet there were no instrumental appliances to aid or to stimulate observation, one who applied himself beyond his fellows to the acquisition of knowledge by the force of intellect was termed a *philosopher.* No matter what he studied,—whether he explored the mysteries of geometry and the magic of numbers,—whether he endeavoured in the recesses of his laboratory to reconstruct the rose from its ashes, or to change to gold the baser products of the earth,—whether he condescended to scrutinize the form and structure of the meanest insect that crawls upon the ground,—or soared into sublime heights of speculation beyond the domain of matter in his efforts to lay hold of a knowledge of the absolute, the good, the true, which with unerring instinct he perceived to be working incessantly among the realities of life, investing man with a mystery he could neither escape from nor lay hold of,—in whichever of these ways his exploring intellect went forth, he was a "philosopher," and his study was "philosophy."

To-day we restrict the term "philosophy" within far narrower limits, having learned with the growth of knowledge that philosophy is neither religion, nor science, nor law, nor medicine, nor literature, but occupies a province of her own, where she reigns supreme—the domain of ethics and psychology.

But while the term philosophy was thus gathering up its borders, and before that process had reached so complete a stage as is the case at the present time, and when it was felt that the phenomena of the material world presented, in themselves, so important a field for study that they could no longer be classed with the very different phenomena of mind, the term "*Natural Philosophy*" came into use for the sake of distinguishing, from philosophy proper, the philosophy that devoted itself to "Nature"--that is, to the world around us. The term is, at the best, a bad one; for surely *man* is as truly part of Nature as are the various forms of lower life, and *mind* as surely natural as the forces of gravitation, heat, magnetism, and electricity. Besides, the term natural philosophy seems to imply that there is a range of *unnatural* philosophy: another error, unless we are prepared to exclude all metaphysics as illegitimate.

In consequence of the imperfection of the term, therefore, it has long been the fashion on the Continent to assign to the science that deals with the so-called natural phenomena, the name of PHYSICS (φύσις, nature.) It is now generally adopted in this country, although some Universities still adhere to the older term. It also has this advantage as a term, of supplying a correlative—*Meta-physics*—for that other domain of mental and moral science to which the correlative of the term natural philosophy did not by any means apply.

The character of Physical Science is essentially twofold, for, since it is based upon a knowledge of the phenomena of the material world, it is obvious that observation and the right use of the outward senses of perception lie at its very foundation; and further, since it professes to give a rational account of the efficient causes of the phenomena of matter, or, more strictly, of the phenomena of material systems under the operations of force, it bears also a theoretical aspect, as requiring and calling forth the exercise of the higher powers of generalisation and inference, to correlate the facts observed, and to elicit from them the reasons for their occurrence. We have, in assuming this position, virtually

defined the science of *Physics* as equivalent to a knowledge of the laws of the phenomena of material systems as affected by force.

But it would be incorrect to assume that observation and inference alone, suffice to lead to a full knowledge of these natural physical laws. To obtain a clear view of the cause of the very simplest natural phenomenon recourse must be had to the method of *experiment*, that, by the severest tests of actual trial, the reason assigned as the efficient cause of a phenomenon may be put to the proof. If an inference be drawn from a single isolated observation, that inference will most probably be incorrect, inasmuch as on the first observation of a phenomenon we are almost if not quite certain to have overlooked some one or more of the important antecedent circumstances. Hence the necessity of multiplicity of observations, and of the artificial variation of the antecedent conditions, in order to discover which of these was essential to the production of the phenomenon observed. And thus, we perceive, by the necessity of the case the science becomes one of *experiment* and *theory*, rather than of simple observation and simple inference. Here those who propose to themselves the study of Physics must remember that no theory is deserving of the name which has not for its basis a firm foundation of observed facts. A temporary theoretical suggestion, made for the purpose merely of attempting to explain some obscure phenomenon, may often serve a useful purpose in the pursuit of truth. But if such a suggestion be not directly founded upon, and applicable to, the work of observation and experiment, it is a mere *hypothesis*, not a genuine *theory*. All modern advances in Physical Science are strictly the result of observation and experiment; here all *à priori* guess work is rigidly and necessarily excluded, as it can only tend to error.

There can be no question that the cause which preeminently tended to retard the progress of a knowledge of nature during the middle ages was the uncontrolled tendency to indulge in all manner of à priori hypotheses and conjectures. High-sounding

names and empty speculations so cumbered the path, that the real simple plain highroad of scientific method,—that of honest, humble, patient observation and experiment—was well-nigh lost; and the face of knowledge was darkened by ignorant presumption until the sixteenth century. Then arose two great men; so great that it is at the present day almost impossible to do justice to the breadth of originality to be found in each: diverse in their nature, yet each typical of one of the two aspects of physical science: Gilbert, the founder of the experimental method of observation; Bacon, the author of the inductive method of reasoning. From these men dates the whole growth of modern scientific method and scientific knowledge.

Newton, great, uniquely great as he was, owed to those who immediately preceded him not a little of that exquisite training of intellect, which, combined with transcendent ability, made him preeminent in his time. Throughout his scientific writings may be traced the effect of the logic of Bacon: some of the most treasured gems of the inductive philosophy being re-set in the new lustre of freshly acquired truth.

And when Newton, apparently adopting it as the motto of his scientific works, wrote: *Hypotheses non fingo*, —"I don't frame hypotheses,"—he indicated that so far at least as his example was concerned he had broken for ever with the unscientific methods of the past. To Newton we owe, besides, those precious *Regulæ Philosophandi* which in his immortal Principia* he has given us, *Rules of Philosophising* containing the whole core and marrow of of the scientific method.

REGULÆ PHILOSOPHANDI.

I. *We are to admit no more causes of natural things, than such as are both true and sufficient to explain their appearances.*

If, therefore, when in a perfectly darkened room, tables are

* Principia Math. Philos., lib. iii.

shaken and tilted, bells flung about, and tambourines are sent flying round with a dim irreligious phosphorescent glow, when there are causes both true and sufficient to explain these "appearances"—these phenomena—any further hypothesis of occult mysterious agencies is both irrelevant and unscientific.

II. *To the same natural effects, therefore, we must, as far as possible, assign the same causes.* To this most important principle we will return presently.

III. *The qualities of bodies which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.*

IV. *In experimental philosophy, we are to look upon propositions, collected by general induction from phenomena, as accurately, or very nearly true, notwithstanding any contrary hypothesis that may be imagined; till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*

It is scarcely possible to lay too strong an emphasis upon the value of such golden guides to the scientific method. And as if further to mark beyond possibility of doubt the emphasis which he laid upon method, Newton added, in the form of a *General Scholium*, the following commentary :—which is here given in his own words.

"*Quicquid enim ex phænomenis non deducitur, hypothesis vocanda* "*est; et hypotheses seu metaphysicæ, seu physicæ, seu qualitatum* "*occultarum, seu mechanicæ, in philosophiâ experimentali locum non* "*habent. In hac philosophiâ propositiones deducuntur ex phænomenis,* "*et redduntur generales per inductionem.*"

Whatever is not deduced from the phenomena is to be termed hypothesis; and hypotheses whether metaphysical, or physical, or magical, or mechanical, have no place in experimental philosophy. In this philosophy the propositions are deduced from the phenomena, and are generalised by induction.

We shall see presently what some of those hypotheses were

which found no place in the method of the experimental philosophy. But first let us make quite sure what we understand by the terms "*phenomena*," "*experiment*," "*law*," and "*theory*."

A *phenomenon* is not necessarily any thing unusual. It may be wonderful, as every thing in nature is if we duly appreciate it. A phenomenon, to go back to its old original meaning, was simply something that happened,—that appeared. We will use it in its original and only true sense to-day. When an apple drops from the tree (as it did when Newton first caught, with a lightning-flash of genius, the significance of the fact), there is a phenomenon, —an appearance. Something has happened, has appeared. The apple is not the phenomenon, neither is the tree, nor yet the ground. *That it should fall* is the phenomenon. So, too, the production of ripples upon a pond, when a stone is dropped into it; the sound of the splash upon the water; the gleam of the rainbow across a stormy sky; the attraction of a needle by a magnet;—are all phenomena, are *physical* phenomena, and fall within the province of experimental investigation. Mayer has well observed that every physical phenomenon is either motion, or the result of motion. This statement is in precise agreement with the modern notion that all the various forces of nature, sound, light, electricity, &c., are "modes of motion," or rather "forms of energy." It brings us, too, face to face with two fundamental facts of consciousness, the ideas of *space* and *time*, since a motion must take place through a certain space, and must occupy a certain time in its occurrence.

An *experiment* is the production or repetition of an observed phenomenon with such variation in the antecedent conditions as shall be deemed likely to lead us to discover which of them was essential to the production of the phenomenon; and which, if discovered, we assume to have been its efficient cause. Here is an instance of the reproduction of a phenomenon indicating the necessary antecedent condition; the lovely colours on the surface of mother of pearl are not colours at all in the same sense as are the colours of flowers: are not due to

the presence in the surface of a definite colouring matter. But that they depend, on the other hand, on the peculiar nature of the surface, is shewn by the fact that an impression in black sealing wax made from the mother of pearl exactly reproduces its characteristic tints. A further proof exists in the experimental production of such tints, artificially, by ruling upon the surface of a piece of glass or metal a series of very fine lines.

Nextly, what do we mean by a *physical "law"*? Well, we must take the trouble to find out what we do mean; or, rather we must take the trouble to find out what Nature means, for the laws are not ours, but Nature's. And these we cannot discover without in the first place searching for ourselves, and exercising our intellectual faculties. Natural laws do not lie upon the superficies of nature: you must dig deeply; and then you do not get the true and correct expression of them all at once, any more than you get finished bars of iron merely by digging, however deeply. When we reflect upon the occurrence of any phenomenon which has happened within the limits of our own observation more than once, we find almost invariably that if the circumstances under which the phenomenon took place at the several times, were similar, the results were similar also. We find perhaps one phenomenon almost or quite always succeeded by another phenomenon. For example, when light is reflected from a flat polished surface, we find the rays leaving the surface at an inclination or obliquity exactly equal to the inclination at which they fell upon the surface. When we hear a peal of thunder, it is our universal experience that, if we had the opportunity of seeing it, a flash of lightning preceded it. When we throw a heavy stone up into the air we find it always to come down again to the earth. Hence the personal evidence of our senses leads us to a *law of experience*, of which these are simple examples: viz., that stones fall to the ground; that thunder is preceded by lightning; and that the angle of reflexion of rays of light is equal to the angle of incidence. We call such a generalisation a "law of experience" because so far it depends,

solely upon the extent or quantity of our experience, and would cease to be a law at all if our experience were to be different at a future time, yet forcing the conviction of its truth upon us the more strongly as our experience is repeated and tested.

But here the inductive faculty of the mind steps in, to strengthen and sustain our experience : for, as we find that such laws of experience, instead of being destroyed or rendered worthless by hopeless contradictions and perplexities, continue to be the expression of our uniform experience, and not of our experience alone, but also that of other men, there grows up an irresistible persuasion in the mind that the relation of cause to effect is a constant, true, invariable relation: one which we can neither alter nor deny. This axiom forms the basis of the second of Newton's Rules of Philosophizing. It is thus stated by Dr. Thomas Young.*

"*The mode of reasoning, in physical science, which is the most generally to be adopted, depends on this axiom which has always been essentially concerned in every improvement of natural philosophy, but which has been more and more employed ever since the revival of letters, under the name of induction, and which has been sufficiently discussed by modern metaphysicians.* THAT LIKE CAUSES PRODUCE LIKE EFFECTS, *or that in similar circumstances similar consequences ensue, is the most general and most important law of nature; it is the foundation of all analogical reasoning, and is collected from constant experience by an indispensable and unavoidable propensity of the human mind.*" This fundamental notion has aptly been termed the "*Principle of Continuity.*† A simple example makes the fitness of the name apparent. The sun rises every day: this is a fact of experience. If some morning the sun were to contradict our entire experience, and decline to rise, here would be a breach of uniformity, of continuity, that would utterly unsettle all our intellectual powers. We could never depend upon our

* Lectures on Natural Philosophy. p. 11. Kelland's edition, 1845.

† See, Sir W. R. Grove in his work on *The Correlation of Physical Forces;* also Tait and Stewart, *The Unseen Universe,* passim.

luminary that the same trick might not be played on a future occasion. But we do *not* find such unnatural breaches of continuity in nature; and the fact that we do not, suffices to convince ourselves of several things: *Firstly*, that there are uniformities in nature which nature herself respects. *Secondly*, that our minds are competent to detect and investigate such uniformities, and so make for ourselves laws of experience. *Thirdly*, that, so far as our intellects have enabled us to read these uniformities, and, so to speak, to put ourselves *en rapport* with nature herself, so far have we the right to say that we understand the *cause* of such a phenomenon All we really mean is, we have been able to detect the physical *law* in accordance with which the phenomenon occurs.

But physical laws may express something more than merely the order in which certain phenomena succeed one another. All accurate science deals not with qualitative phenomena alone, but, and perhaps I may say with truth, chiefly, with the quantity or magnitude of phenomena. Let us spend a few moments upon the consideration of some of the more important of quantitative laws. We have, firstly, several laws of *direct proportion*, in which the magnitude of one antecedent condition strictly involves a corresponding magnitude of another resultant circumstance. Thus the mutual attraction of two heavy bodies is exactly proportional to their masses. The longer the organ pipe, the deeper the note it produces. The greater the stretching weight, the larger is the amount by which an elastic string is elongated. Obviously all the examples under such laws as these require the execution of no more difficult mathematical process than the ordinary proportion sum. Again we have several laws of simple *inverse proportion* The volume of a mass of gas at a constant temperature varies inversely as the pressure upon it. The greater the thickness of the vibrating string, the less is the number of those vibrations per second.

Other laws are much more complex in their expression, and of these we must only here refer to one most important set: they are

laws of *proportion as the inverse squares.* Thus the attraction between two heavy bodies varies inversely as the square of the distance between them. Double the distance, the attraction is reduced to one-fourth; treble it, the attraction diminishes to one-ninth what it was. So, too, the light of a candle, the radiation of a red-hot ball, and the sound of a bell vary in intensity inversely as the squares of their distances from the receiver of them. The same is true of the electric and magnetic attractions: they vary inversely as the square of the distance. The law is true of these because in all cases there is action from a central point upon a surface. Such a law is necessarily true of all forces which radiate from a centre. If the proposition of the United Kingdom Alliance be true (and I am not here to-day either to deny or to defend its truth or falsity) that the drunkenness of a people is exactly proportionate in quantity to the facilities for obtaining drink, then it follows that the drunkenness of a population over a given element of area varies directly as the number of public-houses, and inversely as the square of their distance, (supposing always that the distance be measured normally to the plane of that area.)

It may be that we cannot amid the complication of phenomena always trace the working of a simple law: even the effects of the simplest laws may at times appear contradictory until we understand them and familiarize ourselves with them. Yet the more we have to do with Physical Science the stronger does our conviction grow of their reality and truth.

A *Physical Law* may, therefore, be defined as the generalised expression of our experience with regard to the conditions under which a phenomenon occurs.

The next stage in the scientific method, when once empirical general expressions, or laws have been obtained, is to endeavour to co-ordinate together the various laws by shewing their mutual dependence upon a few simple principles. To do this requires mathematical and logical capabilities of the very first order. He who attempts this work without these essential qualifications may

indeed frame ingenious hypotheses upon which laws can be strung, but they cannot be accounted true theories unless they fulfil the primary requirement of a *physical theory*, that of grouping the various physical laws which they comprise in strict mathematical relation to one another. Thus, for example, Kepler with vast and elaborate patience, and after many disheartening failures, arrived empirically at his three famous laws of planetary motion. But the *nexus* of mathematical reasoning binding them together was not supplied until the genius of Newton, correlating them with the more general laws of motion, exhibited them as necessary mathematical deductions from the simple postulates of his Theory of Universal Gravitation. So, too, most of the empirical laws of Optics, those of the Reflexion, Refraction, and Polarisation of Light, were known before Fresnel combined them together in his* famous Undulatory Theory of Light. Now the test of the truth of a complete theory, as of a temporary hypothesis, is to be found in its deductive applicability to the further discovery of fact. If the theory be true, then certain consequences must necessarily follow. We forthwith proceed to investigate the facts and see whether they bear out our theory. If they do, we step forward to grasp further truths. If not, our theory was no theory at all, only a hypothesis, which we must reconsider, modify, or reject in favour of some other more probable solution, and this we must then again compare deductively with facts. In illustration of this deductive application of theories we may take the case of the motion of comets. These, or most of them, violate Kepler's laws of planetary motion by not moving in ellipses round the sun. But when Newton had once established the main principles of astronomy he was able to prove from his theory that motion in a parabolic orbit was also possible, thus establishing the law of cometary motion and confirming the rightness of his theory. So Poisson, working on the lines of Fresnel's Theory of Light

* That Hooke, Huygens, and Young all accepted the essential truth of the undulatory theory does not detract from the greatness of Fresnel in first giving it complete mathematical expression; nor this from the merit of Poisson and Cauchy in the improvements each imported into the theory.

calculated that the result of diffraction at the edge of a circular opaque disc was such that at the very centre of its geometrical shadow a bright point existed. This incredible result was subsequently verified by Arago, and is not difficult of repetition. So again the main outlines of the theory of Thermodynamics having been laid down by Rankine and Clausius as the result of the experimental laws of the dynamical equivalent of heat, and of the expansion of gases, it became possible to deduce a number of necessary consequences, some then unsuspected,* though of immense importance, and the subsequent verification of them has served to demonstrate the adequacy and rightness of the theory.

Here is another instance. Sir William Herschel discovers a new planet by observation of the skies. Further scrutiny reveals an irregularity in its motions. Deductively applying the known laws, and with calculations profound and intricate, two mathematicians, Prof. Adams, and the late M. Leverrier, independently calculate, not only that the presence of an unknown planet may be inferred, but they even point out its position in the sky. True to the prediction, there the planet is, though, unaided by so powerful an instrument as this deductive method, it might have remained for ever unknown. In precisely similar way did Sir W. R. Hamilton predict, and Dr. Lloyd observe the phenomena of Conical Refraction.† In precisely similar way did Maxwell produce Double Refraction in viscous liquids. "We observe and infer," then, "in order to foresee, and foreseeing, to modify and direct." In this lies the vast superiority of sound theoretical knowledge over that which is merely empirical. The knowledge of the laws of nature puts into our hand the means of using them for the good of society and for the progress of the race:

* Such as the lowering of the melting point of ice by pressure, predicted by Professor James Thomson, and verified by the experiments of his brother, Sir Wm. Thomson.

† A new method of observing this curious phenomenon has recently been arrived at independently by Mr. H. C. Sorby, in the course of his series of beautiful researches with the microscope.

and it was doubtless with some sense of the superiority of such knowledge that the Laureate spoke of—

"Ruling by obeying Nature's powers."

Now observe that the distinction here drawn, is not that altogether false and misleading division of science into "practical" and "theoretical" which is too commonly made by superficial thinkers; it is a distinction between the strictly scientific method as just laid down, and the empirical methods of trial and error which are employed by those who have not had the advantage of a training in the scientific method, and which yet do sometimes yield valuable results. There are, indeed, usually two stages in the progress of every branch of science: the empirical and the scientific. In the former, for lack of knowledge, every expedient is suggested by the imagination of the enquirer. It was by empirical experiment that Dr. Gilbert extended our knowledge of electricity by simply trying if any substances, and what, became like the amber, electrical by friction, and discovered that wax, resin, calcspar, diamonds, and many other substances shared that till then unique property. Then when facts had thus become collected, scientific progress was possible because the scientific method could be applied. The history of the Steam Engine* furnishes us with a remarkable case of empirical discoveries up to the time of the scientific improvements of Watt. But now, the theory of the Steam Engine being known and its theoretical capabilities having been calculated, empirical practice again comes into play to adapt and alter the various portions, until the performance attains in practice the theoretical requirement of excellence. To define these two stages as "practical" and "theoretical" is therefore incorrect. The empirical stage may in one sense be called theoretical, since to make progress here requires a remarkable and unusual fertility of expedient and imagination on the part of the experimenter. None can doubt this who have carefully read the works of Gilbert, of Brewster,

* Vide Rankine, *The Steam Engine*, p. 19.

and of Faraday. On the other hand the stage wherein the strict canons of the scientific method are employed has often proved to be the more truly "practical," as being more fruitful of applications of commercial importance.*

The Scientific method then, starting from observation and experiment, draws inferences, generalises the inferences and produces laws of experience; proves these by deductive applications in which resort is again had to the test of experiment and observation; frames theories to account for the laws, and again deductively applies them, until uniform correspondence of observation with theoretical requirement confirms the truth of the whole.

And here let me beg of you to remember and to write it down in your minds once and for ever in the most indelible characters, that we know nothing whatsoever of physical *laws* except in so far as we learn them from physical *phenomena*. We must grasp the particulars before we can ascend to the generalities. Observation must precede inference. "There is absolutely nothing physical to be learned à priori."†

I am the more particular in dwelling upon this point because of late there has been raised a certain note of dissatisfaction at the methods of modern science, and that in quarters where it cannot well be passed by; a dissatisfaction amounting almost to disparagement or contempt.

To strengthen, therefore what appears to me, though possibly not to all, the obvious verdict of common sense, permit me to

* No man has done more for the practical details of the Electric Telegraph than Sir William Thomson, who is at the same time the accomplished author of much in its most abstruse theory. The Electric Telephone of Graham Bell is an instance of "practical" results from abstract scientific research into the acoustic properties of vibrating membranes, and the theory of the vowel tones.

† Tait "Recent Advances," p. 6.

"A clever man, shut up alone, and allowed unlimited time, might reason out for himself all the truths of mathematics, by proceeding from those simple notions of space and number, of which he cannot divest himself without ceasing to think; but he could never tell, by any effort of reasoning, what would become of a lump of sugar if immersed in water; or what impression would be produced on the eye by mixing the colours yellow and blue." Sir J. Herschel, *Discourse on Natural Philosophy*, p. 76.

appeal to the verdict of the history of the physical sciences. I venture to say that the result of that appeal will be in every instance to shew that whenever men have resolutely followed the path of observation and experiment in their researches into the laws of nature, they have never wandered far from the right appreciation of the law they sought for, never so far as to be beyond recall: while on the other hand—and to this I believe there is no exception—no philosopher who has started in ignorance or in defiance of the simple matters of experience, has, by any flash of genius however lofty or however brilliant, ever enriched the mind of man with an important addition to his knowledge of the forces of nature;—his light has far too often been a mere *ignis fatuus*, bright truly, but shining only to plunge him who follows into quagmires of error.

Thales, whose wisdom six centuries before Christ made his name famous through Greece, was a philosopher and an astronomer. But his astronomy was better than his philosophy, by just so much as its method was the more scientific. By observation, reflection, and inference he had discovered the law of the eclipses; for which brilliant discovery he is justly famous to all time. But when we find that to this fine piece of scientific research he added the brilliant dictum that water was the origin, or, as he expressed it, the mother of all things, we begin to see where and why he erred.

Equally at sea was *Anaxagoras*, who laid down a similar law, but with this difference, that the *air*, not *water*, was the origin of all.

Heraklitus, who came a little later than the time of Thales, had a new notion to propound: namely, that *fire* was the grand original of all things, and in so far as his facts went he was more near the truth than his predecessors. He had grasped a new notion—that of a power acting upon matter; and his greatest argument was one drawn direct from observation; viz., that heat, warmth, fire, were essential to every kind of life and growth.

Then came *Plato*, of whom in the present allotted limits I regret I must not stay longer than to mention, what, after all,

is a most insignificant point in the range of his magnificent writings. His idea of the order of nature was that it consisted originally of the five elements, fire, air, earth, and water, together with the αἰθήρ æther, or upper air. The four principal of these elements held sway over the minds of men for an entire millennium, only to be dethroned by the advent of the Baconian method. The fifth, as we know, has been recently revived in the hypothesis which demands a medium for the transmission through space of those subtle forces which we know to produce upon matter the phenomena of Light, Radiant Heat, Electricity and Magnetism. It is possibly also the medium through which gravitation acts. But none of these modern notions were ever dreamed of by Plato. The ether of modern physicists is a conception wholly different from that of the Grecian sage. The name only is the same, it having been chosen by Dr. Young as one already in existence to define a body of such subtle tenuity as to be no longer to be accounted *matter*. I need not say that Plato's conception of the building of the Universe from these hypothetical elements was wholly fanciful--or let us say speculative. It was an *à priori* conclusion, not an *à posteriori* inference from facts.

But why dwell on these instances? History abounds with such, and we have only to take a very rapid glance over its pages to gather a fair sample of the dicta of philosophers of the à priori school, in interpreting the laws of nature. Had we time we might learn that a man had two ears, two eyes, two nostrils, and one mouth—seven in all—because there were seven tones in music, and seven planets, and seven days in the week. We might learn that the seven planets revolved about the earth attached to seven crystalline spheres, one inside the other like the ivory balls of the Chinese juggler, and which in their scraping and grinding together produced a music so sweet that no mortals could bear it: that stags' horns grew branched because they fed on branches of trees, while cows' horns grew straight because they fed on grass: and yet such statements were gravely made by the high priests of the à priori philosophy! To the limbo of oblivion to which they have

gone we must also consign sundry modern hypotheses that have been weighed in the balance of experiment and found wanting—the 'Corpuscular Theory of Light,' 'Caloric,' 'Phlogiston,' 'the Electric and Magnetic Fluids,' and the 'Odic Force.' Peace be to their ashes.

Turning on the other hand to the experimental method, we must at the outset credit something to Plato's great rival in Ethics, *Aristotle*, which the Aristotelians of later time do not deserve. One of Aristotle's dicta, which in the philosophic jargon of the day concerning the existence of a *plenum* and of a *vacuum*, must have seemed less meaningless then than now, was *that Nature abhors a vacuum.* It is not true, indeed, as Galileo showed; but the great Stagyrite did not make the assertion without at least some show of truth, for before he committed himself to the statement he tried the experiment of weighing a wine-skin inflated with air, and then of weighing it again when empty :—from which experiment unfortunately no conclusion could rightly be drawn, seeing the experiment was in each case conducted in the open air under usual atmospheric conditions. Nevertheless Aristotle had the germ of the true scientific man about him, as his zoology and its really very clever classification of animals shew.

But from that ttme forward experimental science seemed really to be gradually dawning upon the race. *Archimedes*, who lived 287 B.C., besides making several advances in geometrical science, discovered the important principle of specific gravities, and several other physical principles not inferior in value. Then came *Hipparchus* the astronomer, the catalogue-maker of the stars, the first to suggest a method for approximately estimating the distance of the sun; the very father of practical astronomy. After him we must name *Ctesibius* the inventor of Pumps, and *Hero* of Alexandria, the discoverer of the Fountain that bears his name, and of the incipient steam-engine, the Aeolipile. And *Plutarch*, the discoverer of the refraction of light, and *Ptolemy* of Alexandria, author of an excellent treatise on Optics, though when he left the experimental method, and wandered off to the speculative, he

entangled himself in the à priori doctrines of the astronomical system that bears his name, which it afterwards required all the insight of Copernicus and the power of Galileo to overthrow.

But for a thousand years Experimental Science slept. Dim mysticism and the fantastic rubbish of the scholiasts wove a web through which the light of scientific day struggled in vain to penetrate. But when the beams of light once burst through they illumined with an effulgence wholly new and unexpected the resources of the human mind. At the close of the sixteenth century the microscope, the burning glass, the thermometer and the magnet were already known. To our knowledge of the latter, and of the kindred phenomena of Electricity much had been added by Dr. Gilbert of Colchester, a name of which England to-day may be proud. Galileo next enriched the world with the astronomical facts first revealed by the telescope. Then came the influence of the great master-mind of Bacon, whose works mark the inauguration upon a sure foundation of the inductive principles of the new philosophy which had thus been working upwards in channels obscure and despised. From this point in reality dates the vast growth of modern science as we know it to-day. To review its progress in this discourse were simply impossible. It must suffice to name a few of the most distinguished men who have added to our knowledge of facts and thus extended the boundary of natural science. Beginning with Kepler, and Newton, and Hooke, we come to Otto Guericke, and Gay Lussac, Boyle, Black, Rumford, Lavoisier, the Herschels, Young, Dalton, Davy, and Faraday, beside a host of others equally worthy, whose names to-day we venerate and esteem.

Remember what they have done. Think what science was without them, and what she is to-day with them. Look on that picture and on this, and be assured, once and for all, that any and every system of natural science whether it style itself philosophy or not, which is founded upon à priori speculation is doomed to failure and decay; whilst every revelation of the laws and causes that underlie the natural world, founded upon observation and ex-

periment, leads sooner or later to a genuine accession of power to the whole human race for all time.

To patient investigation and not to brilliant flashes of imagination do we owe the steam-engine and the telegraph. To a like origin may we refer the photograph, a miracle of which our great-grandfathers never dreamed. And, in the more abstruse regions of scientific acquisition, we have but to refer to the recent development of spectrum analysis, and of the modern doctrine of Thermodynamics, to point the moral of the tale.

I spoke just now of a symptom of revolt from this the experimental—the positive method, if I may so term it,—of thinking and reasoning. No one German thinker has perhaps in his own sphere exercised more influence on English letters than has Hegel.* Yet Hegel's philosophy was childish in the extreme where it dealt with natural phenomena. He possessed neither the patience nor the impartiality of the scientific method; and this lack extended itself to his judgments upon scientific men. An echo of this superficial condemnation I met with a few days ago in a striking passage on Modern Science in Buckle's "History of Civilisation," vol. iii., p. 379.

"I cannot but regard as the worst intellectual symptom of this great country (England) what I must venture to call the imperfect education of physical philosophers, as exhibited both in their writings and in their trains of thought. This is the more serious, because they, as a body, form the most important class in England, whether we look at their ability, or at the benefits we have received from them, or at the influence they are exercising, and are likely to exercise, over the progress of society. It cannot, however, be concealed that they display an inordinate respect for experiments, and undue love of minute detail, and a disposition to overrate the inventors of new instruments and the discoverers of new but often insignificant facts. Their predecessors of the seventeenth century, by using hypotheses more boldly, and by indulging their imagination more frequently, did certainly effect greater things, in comparison with the then state of knowledge, than our contemporaries, with much superior resources, have been able to achieve. The magnificent generalisations of Newton and Harvey could never have been completed in an age absorbed in one unvarying round of experiments and observations. We are in

* See Tait, "*Recent Advances,*" p. 7., for a characteristic specimen of Hegel's puerility in matters of scientific knowledge.

that predicament that our facts have outstripped our knowledge, and are now encumbering its march."........."In vain do we demand that they should be generalised and reduced into order. Instead of that, the heap continues to swell. We want ideas, and we get more facts."

Let me ask you to tell me fairly and honestly, is not the history of experimental science in itself an ample reply to the vague charges of the historian of civilisation. In matters of scientific import, I repeat, the tested experience of trained thinkers, is the only safe basis for inference. Scientific induction must proceed from the *known to* the *unknown*, not from the unknown to the known. And this Newton implied when he laid down that we are to admit no more causes of natural things than such as are *true* as the very first principle of the scientific method.

Let us now turn to some of the more special methods of physical science which have been of service in the progress of acquisition of facts. They may be ranged in a few groups for convenience of discussion.

Firstly. We will mention as the least methodical of all, *Casual Observation.* Some person, history tells not who, must *first* have observed the attractive properties of the loadstone; and so laid the foundation of magnetism. Somebody must first have tried the experiment of rubbing amber, and found it electrical. Some one must first have observed the rise of liquids in capillary tubes. Who can say what may not result from the casual observation or the empirical experiment of the honest seeker after truth. These "*glaring instances,*" as Bacon would have styled them, are now expanded into whole sciences. There are glaring instances to the present hour almost as unique. There is that curious phenomenon of the production of sound from a hot rocker of copper laid down upon a cold block of lead, commonly known as Trevelyan's experiment, for which yet no explanation has been offered to which exception cannot be taken. There is the pyro-electricity of the tourmaline, too, a "glaring instance" of perfectly priceless significance, yet most obscure and unexplainable.

Secondly. There are *Methods of Comparison,* only available to those whose knowledge of the natural sciences is very extensive

and who can bring to bear facts scattered over a very wide range. Bacon has well said that "no natural phenomenon can be adequately studied in itself alone, but, to be understood, must be considered as it stands connected with all nature." That comparison over a wide range of facts does lead to physical discoveries, we have but to point to the splendid researches in Physiological Optics and Physiological Acoustics of Helmholtz, at once surgeon, mathematician, musician, and physicist; a very giant of intellect. So, too, the last advance of the science of telegraphy, the articulating telephone, is the invention of one of the best living authorities upon the organs of speech, and who adds to other scientific qualifications that of being an electrician also.

Thirdly. We have *Methods of Precision*, which are indeed of several kinds. There is a certain kind of precision created by the necessities of manufacture, to which many empirical improvements in the telescope and the steam engine, and in the processes of photography are due, yet which have proved substantial scientific gain. There are also methods founded upon new systems of measurement; of which the system of electrical units so extensively employed in testing telegraphic lines is an example. Of the phenomena of heat but little was known until science became possessed of a standard scale for measuring temperatures, and a unit for the measurement of heat quantities. Very closely related to these are the methods of precision involved in the use of more accurate instruments. Thus the introduction of the chemical balance in the hands of Lavoisier, revolutionized chemistry, and set it upon its present basis. So Wollaston's reflecting goniometer introduced into the science of crystallography a precision before unheard of, and rapidly exposed some errors resulting from the employment of a less refined instrument of measurement. Whitworth's famous measuring machines are splendid examples of the degree to which precision may be carried out. In order the better to observe slight movements of a magnet, Poggendorff first thought of the expedient of attaching to the magnet a light mirror whose slightest movement should be followed by the rays of light it reflected.

By such a means the excessively fine diurnal variations of the magnet can not only be followed, but actually recorded by a self registering photographic apparatus.

Fourthly. There are *Methods* of *Analogy*. It is found as a matter of experiment that sound and light obey similar laws of reflexion and refraction. The analogy thus existing between them has been widely extended, for we find that both are forms of wave motion; both travel in straight lines across a room, both can be brought to a focus by suitable lenses, and in both the phenomena of interference can take place. So too, analogies exist between light and radiant heat, analogies so strong as to amount almost to identities. All the laws of polarization of light, for instance, apply also to the invisible rays of heat. There are analogies, too, between heat and electricity which have been fruitful sources of discovery. One of these is that any substance which is a good conductor of heat, is also a good conductor of electricity, and vice versâ. Analogy, unfortunately, is not always a trustworthy guide, and may be pushed too far: it is highly suggestive as a means of research, but the suggestions of analogical reasoning are not always fulfilled in the fact. The analogy between sound and light, for example, was pushed too far by Newton, when having discerned, as it seemed to him, seven elementary colours he compared them to the seven notes of the gamut.

Fifthly. There are *Methods of Hypothesis*, which if rightly used, not *à priori* but *à posteriori*, and in connexion with known facts are of the highest value.* Physicists habitually make use of provisional or temporary suggestions framed upon very slender experience in order that the further test of experiment may be deductively applied. Yet this "scientific use of the imagination," as Tyndall has well termed it, is fraught with danger; since all scientific men do not, unfortunately, appear to have the courage

* Compare Sir J. Herschel, *Discourse on Natural Philosophy*, p. 204. "A facility in framing them (hypotheses), if attended with an equal facility in laying them aside when they have served their turn, is one of the most valuable qualities a philosopher can possess."

to relinquish hypotheses they may have framed, even when facts are against them. Can any one doubt at the present moment what will be the opinion of posterity upon the question of spontaneous generation, or hesitate as to which way the balance of evidence turns between M. Pasteur and Dr. Bastian? Yet it seems well nigh useless to hope that Dr. Bastian will abandon a position which all save himself pronounce untenable. Nevertheless an erroneous hypothesis may in the long run do good by stimulating thought and observation. As a curious instance of a right result from a wrong hypothesis, we may remember that the problem of making an achromatic telescope was abandoned in despair by Newton. But Euler pointed out that this must be possible, alleging in evidence the achromatic combination of the eye. Forthwith Dollond proceeded to construct an achromatic telescope, and then discovered that the eye could not be achromatic (as indeed it is not) since it did not conform to the laws of achromatic refraction.

Sixthly. There are *Residual Methods.* Sometimes it may happen that, in a series of phenomena all obeying the same main law, there are found some slight but anomalous variations, which on careful examination are proved to be genuine variations, and not errors of observation or of measurement. In such a case there is evidently a residual cause at work, which must be investigated. Such residual phenomena abound in every department of science, and they are the finger-posts of new discoveries: every exception to a physical law—*and I know of no law to which there are not exceptions more or less clearly admitted*—indicates the existence of some still hidden truth only awaiting patient application of the scientific method to drag it from its obscurity. Mention has already been made of a famous discovery resulting from this method, namely the prediction of the planet Neptune from the anomalous movements of the planet Uranus. The whole science of Spectrum Analysis has arisen from two long neglected residual phenomena; the presence of certain dark lines in the sun's spectrum first seen by Wollaston—the *residuum* of one of the methods of precision in which his researches abound; and the

coloration imparted to flames by certain chemical salts, of which Melville, Talbot, Herschel, and Brewster had already perceived in part the significance. Success in following out the *residua* of precise observation* appears to be a faculty peculiarly developed in individuals. It was richly possessed by Boyle, Wollaston, Faraday and Brewster.† Of living men, I may, without being invidious, name Mr. Crookes, to whom science owes the metal Thallium, and the Radiometer, as the fruits of investigation into residual phenomena.

Seventhly. We must give a hasty glance at the methods which may more or less strictly be termed *Mathematical Methods.* This is not the place to do more than refer to the modern methods which have been forced upon mathematicians by the imperious requirements of physical principles. Since Descartes invented the method of Coordinate Geometry, and Newton the Calculus of Fluxions, there have been several new methods introduced into pure mathematics, amongst which may be named the Calculus of Finite Differences, the Calculus of Probabilities, and the Calculus of Quaternions. One general tendency must not be overlooked; it is in the direction of expressing physical facts in the language of geometrical rather than of purely analytical symbols. The like tendency exhibits itself in a subordinate and simpler case in the frequent substitution in physics of the graphical for the tabular method of exhibiting a collective series of numerical data. The method of Probabilities would deserve more than a passing notice were this admissible here. One form which it takes is an invaluable method for determining the probable error of a series of observations, and known as the method of Least Squares.‡ The

* Compare, on the subject of Residual Methods, Herschel, *op. cit.* p. 156, and Thomson and Tait, *Elements of Natural Philosophy*, p. 108.

† It is scarcely possible for the student to gain a better knowledge of the scientific method than by carefully reading the experimental researches of such masters as Faraday, Graham, Brewster, and Regnault, as recorded in their original memoirs and papers. Abbreviated accounts of their discoveries are comparatively useless to this end.

‡ Those who desire to inform themselves of the mathematical basis of this method should consult Sir George Airy's *Treatise on the Algebraical and Numerical Theory of Errors of Observations.*

method of probabilities, as applied to the statistical determination of the averages of quantities has also led up to the Kinetic theory of gases, and will probably yield abundant results in other parts of science.

The *Graphical Method* of exhibiting observations is too valuable to be dismissed with a bare mention. All numerical quantities may be represented by lines of certain lengths. The charts of variations in the height of the thermometer and barometer which are now so familiar to us are instances of this method. They exhibit directly to the eye what otherwise must be drawn from a heap of figures by an effort of the mind. They possess the additional advantage of being frequently obtained directly from nature by self-recording mechanism. There are self-registering Barometers, Magnetometers, Anemometers and Thermometers. Watt early applied the method to the indicator of the steam engine, which itself draws the diagram expressing the efficiency of the engine at each stroke. When applied to the expression of physical data in the form of a *curve* described about rectilinear coordinates it may be made to indicate in the most distinct manner the existence of residual variations, and residual curves can, moreover, be constructed with special reference to the residual phenomena. Now when the mathematical properties of such a curve are known beforehand, the law which is obeyed by the quantities expressed in the diagram is also known. Hence the graphical method is of great assistance in the discovery of mathematical laws: and it has the merit of diminishing the chances of an accidental error of observation. All curves, in fact, which are produced by natural phenomena, contain in themselves the geometrical expression of the mathematical laws that have operated in their production. The forms of the curves assumed by iron filings when sprinkled above a magnet, are the precise expression of the laws of magnetic attraction, varying directly as the strength of the magnet-pole, and inversely as the square of the distance. The parabolic path of a projectile through the air, or of a jet of water from a hose, and the curve of a chain

as it hangs from point to point, equally declare the laws of gravitational force, and indeed invite our wondering amazement that the mathematics which are by us so laboriously acquired, are the inherent and natural property of inanimate objects. In precisely similar manner there can be no doubt that the natural curves of the branches of trees express the mathematical laws of the forces at work in its growth, though we do not yet sufficiently know what these are to calculate, *à priori*, their form.

The application of mathematical methods to the problems of physical science widens enormously the field of investigation; yet at the same time the obvious tendency to simplify the axioms and postulates of the sciences, and to reduce them all to a few simple notions of number, quantity, time, space, energy, &c., is a sure indication that ere long other sciences, not as yet capable of exact mathematical treatment,—chemistry, crystallography, meteorology, will be included in the numerically calculable operation of physical laws.

After the repeated illustrations I have given of the operation of the scientific methods, it seems scarcely possible that an intelligent listener could doubt of their utility. Nevertheless, as Bacon has remarked, the test of a science is its utility. And since the scientific method is itself a science, it must abide by the test. But if we owe to the method not only the safety lamp, the steam engine, the lighthouse and the telegraph, but also owe whole fields of fresh knowledge as yet in their infancy, and probably hereafter capable of equal service to society and to the civilizing forces of the race, it can scarcely be our place to entertain seriously such a query. Franklin was once asked what was the use of electricity. "What is the use of a baby?" was his half contemptuous rejoinder. And the most insignificant of the results of the scientific method is not to be despised, any more than the first insignificant elements of electric science.

As a mental and moral training, the pursuit of the scientific method is absolutely priceless.* Just think what is required of

* I wish to take this opportunity of recommending all students of Physical Science to read, and to re-read, Professor Stanley Jevons' masterly work,

him who would accurately perform a single crucial scientific experiment. It is a moral and intellectual training second to none. The will must be brought into active and perfect obedience. We shall have patiently to compare, to count, to calculate; every one of these intellectual operations requiring an effort of will to maintain the attention and direct it to the problem before us. We have to keep our purpose steadily in view, and not to swerve from it. We have to practise decision, precision indeed, which in an investigation of great minuteness and accuracy would require to be the more trenchant and exact. We have to attend without hurry, without impatience, without alarm, to the various details of our experiment; and this alone would constitute, were it the habitual manner of our studies, a most valuable training. Above all we have to be clear and just. In no department of human learning, is absolute, vigorous, and unswerving justice more indispensable than to the student of Physical Science. Let him try to *alter*, or *improve*, or *correct* his experiments as he will, he must be just to himself, true to that which he sees, or he will never make progress. A keenness of moral integrity is requisite, equal to that demanded of any man in any study. The 'Idols' of the 'Market' and of the 'Den' must be alike overthrown He who will be warped by prejudice, by passion, or by fear, cannot investigate nature rightly. He must pluck them up, *pinguis radicibus*, or he will be overthrown by them. He cannot rise to the scientific method, nor to the ideal of morality which it demands. He is incapable of science. The scientific investigator has before him (as has been said) "but one desire,—to know the truth:—but one fear—to believe a lie." *

And when his further studies lead him on to higher and more occult problems; when the beauty, the inevitableness of natural

The Principles of Science, in which is developed with admirable ability, and in full detail, all that I have desired to bring before those to whom this Lecture is addressed. While I acknowledge my indebtedness to the author of that work, it is but right to state that I have purposely avoided consulting any portion of his book since this discourse was taken in hand.

* Tyndall, *On the Scientific use of the Imagination.*

law dawns upon him as he traces, from point to point, and from system to system, the workings of the mystery that surrounds him on every hand, in the air he breathes, the earth on which he treads, ay, and also in the life of even the meanest insect upon his path; then the emotions which these things arouse within his breast, fill his mind and possess his spirit; emotions, I venture to say, no less pure, or true, or real, than those excited by the most thrilling piece of history or romance.

It is for reasons such as this that I maintain the priceless value of the scientific method in intellectual training. "What is the hardest task in the world?" asked Emerson,* in one of his less happy moments. And he gave the reply "To think. I would put myself in the attitude to look in the eye an abstract truth, and I cannot." Perhaps the American sage would have found the task less hard had he tried earlier the easier task of looking in the face a concrete truth, by the perception of which the power of perceiving abstract truth is alone to be acquired. I think it is Arnold who says—though I cannot lay my finger upon the passage—that no good teaching can possibly be dogmatic. Mr. Ruskin has maintained† the precise opposite. Physical Science holds the golden mean between these two opposing statements. There is and must be here an absolute and stubborn dogmatism as to ascertained facts: there cannot, and must not, be the shadow of dogmatic assertion about any thing that does not repose upon ascertained fact: for that is not science; it is speculation; it is hypothesis; it is none of ours. The Hypothesis of Darwin (it is sometimes loosely called the Darwinian *theory*, though not a theory at all as previously defined) concerning the Origin of Species, is a most wonderful and successful piece of inventive suggestion, and has almost revolutionized the biological sciences. But it is none the less hypothesis. I should be sorry to be obliged to disbelieve it. I should be sorry to be dogmatically obliged to believe it. The fact is, as Faraday, the great, the

* *Essays*, p. 235.

† *Modern Painters*, vol. iii., preface.

good, once remarked :* "*It is not the duty or place of a philosopher to dictate belief, and all hypothesis is more or less matter of belief; he has but to give his facts and his conclusions, and so much of the logic which connects the former with the latter as he may think necessary, and then to commit the whole to the scientific world for present, and, as he may sometimes without presumption believe, for future judgment.*" These are noble words. "It is not the duty or place of a philosopher to dictate belief." Neither is it his place or duty to dictate unbelief. It is with simple proven facts, and their logical consequences, not with beliefs, or hopes, or fears, that, as a philosopher, he has to deal. If he goes beyond this, he has exceeded his place and duty, has begun to play another part. Beliefs, and hopes, and fears, and loves, and hates make up, indeed, a great part of the sum total of life; for life consists, not in the acquisitions, material or intellectual, which a man has or seems to have. But the student of physical science is not occupied with these, though that is no reason that he should ignore the fact of their existence. The question of belief or disbelief † does not enter into his work. If a fact exists, there it is; beyond question of belief or disbelief. It is, with him, not a matter of *belief* that magnets attract iron, or that there is oxygen in the air, or that sound is the result of certain vibrations: for he knows that these are facts, and will remain facts whatever he or any one else may choose to believe or disbelieve about them. Ask a question of a friend upon any trivial circumstance, and how often you will receive the answer "*I believe so,*" when he is quite uncertain: if, however, the facts are clearly known to him, he says, "*I am certain that this is so,*" and it is taken out of the region of belief and disbelief. If a person claiming to speak from a scientific standpoint says to me "*I want you to believe in a physical connexion between sunspot periods and Indian famines,*" my reply is, this is no matter for belief; I will not believe or disbelieve your proposition; but I ask you to produce your *facts*, and until they

* Philosophical Magazine, 1866.

† For it must be remembered that Belief and Disbelief are the same attitude of mind: that of accepting something as true or false for some other reason than that of demonstrated fact.

establish the point I shall treat the whole thing as a mere hypothesis, open to doubt; for sooner or later, wherever the truth lies, it will come out. If in this spirit we follow out the scientific method we shall not go far wrong in tracking out the subtle details of any one of the varied departments of physical science. There are mysteries enough unsolved to make us sure that we have not come to the end of all that is yet to be discovered, nor are we near it. The well of Truth is sunk deeper in space and in time than that we should fathom it even with the best appliances that twenty centuries of historical experience upon this little globe can yet boast of. And the further we penetrate and explore, and the more we heap up to ourselves the treasures of scientific knowledge, the more surely do we become persuaded of the aptness of that beautiful simile of Newton's; that he who has learnt most widely and most deeply is yet but as a child gathering pebbles under the blue sky, upon the shores of a boundless ocean.

T. KERSLAKE AND CO., QUEEN'S ROAD, BRISTOL.